

# Chapter 8

## A 4D Indicator System of Count, P Rate, G Rate and PG Rate for Epidemiology and Global Health



Xinguang Chen, Bin Yu, and (Din) Ding-Geng Chen

**Abstract** How to end the HIV/AIDS epidemic is a typical global health question since the impact of HIV/AIDS is global and it cannot be ended without collaborative global effort. In this chapter, a new measurement system is introduced to inform HIV/AIDS control cross the globe. All countries with data available on area size, total population and total number of persons living with HIV (PLWH) were included, yielding a sample of 148 countries. Four indicators, including the *total count*, population-based *p rate*, geographic area-based *g rate* and population and geographic area-based *pg rate* were used as a 4D system to describe the global HIV epidemic. The total PLWH count provided data informing resource allocation for individual countries to improve HIV/AIDS care; and the top five countries with highest PLWH count were South Africa, Nigeria, India, Kenya, and Mozambique. Information from the remaining three indicators provided a global risk profile of the HIV epidemic, supporting HIV/AIDS prevention programming strategies. Five countries with highest *p* rates were Swaziland, Botswana, Lesotho, South Africa, and Zimbabwe; five countries with highest *g* rates were Swaziland, Malawi, Lesotho, Rwanda, and Uganda; and five countries with highest *pg* rates were

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Barbados, Swaziland, Lesotho, Malta, and Mauritius. According to pg rates, two HIV hotspots (south and middle Africa and Caribbean region) and one HIV belt across Euro-Asian were identified. In addition to HIV/AIDS, the 4D measurement system can be used to describe morbidity and mortality for many diseases across the globe. We recommend the use of this measurement system in research to address significant global health and epidemiologic issues.

**Keywords** Global health research · HIV/AIDS epidemic · Geographic area-based g rate · Geographic and population-based pg rate · Global mapping

## 8.1 Introduction

One fundamental task for epidemiology, particularly global health epidemiology is to provide good tools to extract information from data for accurate understanding of the level, risk factors of a disease and its impact on population health (Rothman, Greenland, & Lash, 2008; Szklo & Nieto, 2018). In addition to the disease epidemiology, such information is essential for public health planning and strategic decision-making, prevention intervention programming and program evaluation (Bayer & Galea, 2015; Chen & Wang, 2017; Khoury, Iademarco, & Riley, 2016). Since the beginning of epidemiology and public health, two indicators most commonly used in research have been (1) the total count that informs us about the total number of persons who suffer from or died of a disease; and (2) rate that reflects the risk of a person suffering from or being died of a disease.

During early stages when a disease has just started to appear, the number of new cases is counted periodical (i.e., daily, weekly, or monthly); the counts are then accumulated to show the progress of the disease epidemic in a population, such as SARS (Wikipedia, 2019), Ebola (Meltzer et al., 2014), and bird flu (Ferguson, Fraser, Donnelly, Ghani, & Anderson, 2004) as being commonly practiced today. When a disease becomes an epidemic and lasts for long time to affect more and more people in a population, annual count of persons who suffered from or died of the disease is used to monitor the epidemic, such as the number of persons living with HIV/AIDS or died from AIDS each years (WHO, 2018). In vital statistics, the number of persons suffered from or died of different causes of diseases is documented on an annual or biannual basis as shown in many statistical yearbooks.

The headcount of a disease as an epidemiologic measure provides information very useful for decision-making at the population level. It is the basic data used in planning and decision-making to allocate resource for disease treatment and prevention (Bautista-Arredondo, Gadsden, Harris, & Bertozzi, 2008). For example, if a total of 1200 persons are diagnosed with cancer. Assuming that the government expenditure for treating one cancer patient per year on average is \$15,000, a total of \$18 million ( $\$15,000 \times 1200$ ) every year must be allocated in the country's budget for treating all the cancer patients. In the United States, the Centers for Disease Control and Prevention uses this method to plan its Healthy People 2030 for resource allocation for all public health programs, and more details can be found at the URL: <https://www.healthypeople.gov/>.

Despite the usefulness, information provided by headcount is inadequate for measuring and comparing risks of a disease across regions and jurisdictions with a country and across countries in the world. This is because given the same level of likelihood for a disease to spread, the head count of a disease will differ for countries and regions with different population sizes. A country or region with a larger population will have more people at risk of suffering from a disease than a country or region with a smaller population given the same risk level. Epidemiologists have overcome the limitation of headcount data by using the indicator rate. Methodologically, a rate is a measure that adjusts the impact of population size in assessing disease risk (Chen, 2017; Chen & Wang, 2017). Disease rates therefore provide a measure more informative than disease count for comparison across regions within a country, and across countries in the world.

The two epidemiologic indicators, headcount and disease rate described above have been used almost everywhere from research to practice, including the World Health Organization, governmental and nongovernmental agencies; researchers and students in institutes and universities; and public health workers in communities and neighborhoods. While appreciating the value and utility of the two epidemiologic indicators, we cannot overlook their limitations. Although measures of disease rate are more informative than measures of headcount with regard to informing levels of risk of a disease at the population level, both headcount and disease rate cannot address another key factor—the size of geographic areas people reside (Chen, 2017; Chen & Wang, 2017). To fill in this methodology gap, in this chapter, we will introduce a new measurement system by incorporating geographic area size into measurement. We illustrate the new measurement system using the global HIV epidemic as an example.

## 8.2 Ending the HIV/AIDS Epidemic by 2030

The epidemic of the human immunodeficiency virus (HIV) and the acquired immunodeficiency syndrome (AIDS) is a typical global health problem (Chen, 2014; Merson, Black, & Mills, 2012). Worldwide, the number of persons living with HIV (PLWH) has totaled 36.9 million (WHO, 2018). The impact of HIV/AIDS on human health is global; therefore, effective HIV/AIDS control and prevention requires collaborative and global efforts (Deeks et al., 2016; International Aids Society Scientific Working Group on H I V Cure et al., 2012). No one individual country is immune to HIV infection and no one individual country alone can get rid of the HIV epidemic without involving other countries and agencies in the world.

In fighting the HIV/AIDS epidemic, two strategies are widely used: (1) Antiretroviral therapy (ART) and (2) prevention intervention programs. The first strategy is designated for treating persons living with HIV (PLWH) whose viral load has not been suppressed and this strategies has been widely implemented across the globe (Tanser, Barnighausen, Grapsa, Zaidi, & Newell, 2013; UNAIDS, 2017a). In addition to treading the infected, appropriate implementation of ART, such as treatment as prevention (TasP) can help PLWH to achieve viral suppression,

reducing the number of infected persons who can infect others (Cohen, 2011; Granich et al., 2010).

The second strategy of prevention is for all persons who are at risk for HIV infection, including the PLWH who can be re-infected (Lyles et al., 2007). These programs include school- or community-based interventions for general population and venue-based high-risk population intervention (e.g., drug users, men who have sex with men, sex workers). To develop and implant either an ART program or a prevention intervention strategy, adequate data are always needed for strategic planning, evidence-based decision-making, and objective program evaluation (Courtenay-Quirk, Spindler, Leidich, & Bachanas, 2016; H. I. V. Modelling Consortium Treatment as Prevention Editorial Writing Group, 2012; Marsh & Farrell, 2015).

Based on the epidemic of HIV/AIDS and success in treatment and prevention, the Jointed United Nations Program on HIV/AIDS sets the goal to End the AIDS Epidemic by 2030 (UNAIDS, 2014b). To achieve the goal, the UNAIDS further asked that by 2020, 90% of PLWH know their HIV status, 90% of diagnosed PLWH receive sustained ART and 90% who receive ART have their blood viral load suppressed (90-90-90 strategy) (UNAIDS, 2017a). Pursuing these goals requires collaborative efforts to plan and deliver patient-centered ART and population-centered (both the general and at-risk population) prevention programs to reduce the risk of HIV transmission by all possible venues, including sexual contact, needle sharing and vertical maternal-child transition (AVERT, 2017; CDC, 2018b; National Health and Family Planning Commission of PRC, 2015; WHO, 2017).

### 8.3 Four-Dimensional Measurement System

#### 8.3.1 *Two Conventional Measure of Headcount and P Rate*

From a precision public health perspective (Chen & Wang, 2017; Khoury et al., 2016), relevant and sufficient information is essential to plan and implement HIV/AIDS treatment and prevention strategies to achieve the goal of ending the HIV/AIDS epidemic by 2030. For example, the number of PLWH by country is needed for resource allocation to achieve the 90-90-90 proposed by UNAIDS. If it costs on average \$1000 to treat one PLWH per year, a total of \$39 billion will be needed to treat all the 39 million PLWH in the world. There were 850,000 PLWH in China in 2015, which meant China needs \$850 million per year to treat these infected persons.

Despite great significance, information conveyed by the number of PLWH for individual countries provides limited information about between-country differences in the risk of HIV transition because of population size (Chen, 2017; Chen & Wang, 2017). In addition to risk factors, the total number of PLWH in a country is directly related to the population size. For example, in 2015, there were 850,000 PLWH in China and 830,000 in Brazil (see Appendix to this chapter for detailed data). If larger number of PLWH meant higher risk of HIV transmission, people

in China may face a higher risk than people in Brazil. However, the population of Brazil was 208 million, only about 15% of 1.4 billion, the total population in China. We cannot determine whether the risk of HIV transmission is higher in China or in Brazil using only the measure of total headcount of PLWH.

To more accurately assess the risk of HIV transition, a population-based measure has devised by dividing the number of PLWH with total population. In our 4D measurement system, this population-based measure is termed as *p rate* (Chen & Wang, 2017). Epidemiologically, a *p rate* is more accurate than a headcount to assess between-country differences in risk of HIV transmission because it quantitatively adjusts the differences in population sizes. Following the same example in the previous paragraph, the *p rate* for Brazil was 3.993/1000 population, 6.4 times higher than 0.630/1000, the *p rate* for China. Therefore, based on the *p rates*, we can conclude that the risk of HIV transmission is 6.4 times higher in Brazil than in China.

### 8.3.2 Two New Measures of G Rate and P Rate

*P rate* has been one of the most commonly used measures in epidemiology and global health. Despite its advantage in controlling for population size, *p rates* for different countries are confounded by the geographic area size of a country. Again using PLWH as examples: the total number of PLWH in 2015 was about 220,000 in two countries: Swaziland and Mexico; however, the total area was 172,000 km<sup>2</sup> for Swaziland, much smaller than 19,440,000 km<sup>2</sup>, the geographic area size of Mexico. If people from the two countries reside on a same size of a geographic area (say, like Swaziland), the risk of HIV transmission would be 113 times (19,440,000/172,000) higher in Swaziland than in Mexico. To consider difference in geographic area size like the *p rate* for population size, *a new and geographic area-based measure has been developed and named as g rate* (Chen, 2017; Chen & Wang, 2017).

*G rate* of a country/place was defined as the ratio of total events over the total geographic area size of the country/place. *G rate* can be defined for many medical and health events. For example, *g rate* can be defined and estimated for new infections of a disease to evaluate the risk of disease transmission; *g rate* can also be defined and estimated for total deaths by country to assess risk of mortality; and certainly *g rate* can be used to measure PLWH and compare between-country differences in the risk of HIV transmission. While a *p rate* provides a measure that has epidemiologically adjusted the confounding from different population sizes; a *g rate* provides another measure that has epidemiologically controlled the confounding from the different geographic area sizes. With a *g rate*, the significance of geographic areas in disease epidemiology (Sattenspiel, 2009) can be assessed quantitatively.

Inspired by *p rate* and *g rate*, a natural extension would be to consider both population size and geographic area to assess the morbidity and mortality of any health conditions. It is based on this line of thought, another new measurement – *pg rate* has been developed (Chen & Wang, 2017). As the name suggests, a *pg rate*

of a health event for a country is defined as the ratio of total count of the event over both the total population and the total geographic area of the country. Since the confounding effect from both population and geographic areas are adjusted, pg rate provides a measure better than p rate and g rate alone to assess the epidemiology of any medical and health event across countries in the world.

The four epidemiological measures of headcount, p rate, g rate and pg rate consist of a new 4D measurement system. This 4D assessment system extends the conventional measures and can be used in assessing many medical and health conditions to advance both research and practice in global health and epidemiology.

## 8.4 An Example of Global HIV Epidemic

To demonstrate the 4D measurement System and its application, we analyzed data for PLWH in 2015. The method can be used for study any other diseases.

### 8.4.1 Materials and Method

*Persons living with HIV (PLWH).* These data were limited to 2015 and were derived from multi-sources, including the UNAIDS, government websites and different governmental reports. Data for a total of 148 countries with data available on PLWH were included. Of these countries, data for 107 countries were derived from the UNAIDS, and three from the government report or HIV/AIDS data hub, including the United Kingdom, China and Laos (UNAIDS, 2016, 2017b). For the remaining countries with no data in 2015, data for most closed years were used. For example, 2014 data were used for Canada, Fiji, Montenegro, Netherlands, New Zealand, and Singapore were derived from the Progress Report by Country (UNAIDS, 2014a); 2014 data for Estonia were derived from the Evaluation Report of the World Health Organization (WHO Regional Office for Europe, 2014); data for the United States in 2013 were from the Centers for Diseases Control and Prevention (CDC, 2018a); and data for Guinea-Bissau in 2012 were derived from the UNICEF (UNICEF, 2013).

*Geographic area size by country.* Data for the size of geographic area ( $km^2$ ) of individual countries are extracted from the World Bank Data Depot (World Bank, 2015a). This is a great official source of geographic data for countries in the world, and has been globally accepted. Data from this source are also widely used in statistical analysis and visualization to address global issues (Redding & Venables, 2004).

*Population data by country.* The population data by country were also derived from the World Bank Data Depot (World Bank, 2015b). The data stored are compiled by the United Nations Population Division, and the population data in this source are based on multi-official sources, including census reports and other statistical publications, the population and vital statistic report by census bureau of various countries in the world.

### 8.4.2 Estimation of P Rate, G Rate and PG Rate

P rate, g rate and pg rate for the 148 countries included in this example were computed respectively using the following three equations:

$$p \text{ rate} = \frac{N}{P} \text{ (per 1000 population)} \quad (8.1)$$

$$g \text{ rate} = \frac{N}{A} \text{ (per 100 km}^2\text{)} \quad (8.2)$$

$$pg \text{ rate} = \frac{N}{P \times A} \text{ (per million population} \cdot \text{100 km}^2\text{)} \quad (8.3)$$

Where  $N$  represents the number of PLWH,  $P$  represents the number of population, and  $A$  represents geographic area size.

The total population and geographic area, the total counts of PLWH, and the calculated p rates, g rates, and pg rates for individual countries were included in Appendix.

### 8.4.3 Geographic Mapping

The four epidemiologic indicators by country each were mapped globally, including the headcount of PLWH, and the calculated p rates, g rates and pg rates using the software R. Three R packages for mapping were used, including the “maps”, “mapproj” and “ggplot2”. A dataset “worlddata” was thus created by extracting geographic information of individual countries (country name, longitude, latitude) from the “maps” and merged with the derived data of the population size, geographic area, count of PLWH, calculated p rate, g rate and pg rate by country.

After data preparation, we created a world map using the dataset “worlddata”. Following the National Standard Map Services, we used the “ggplot2” with “rectangular” option and orientation (latitude = 90, longitude = 150, rotation = 0) and “mapproj” to create the world map. A color scale was used to represent different levels of each PLWH indicators by *five* percentiles. Greenland located in the far north was not included in the mapping because of the lack of HIV data. R codes for the geographic mapping are available from the author Bin Yu upon request.

## 8.5 Results

With data from the 148 countries included in this analysis, worldwide an estimate of 35,426,911 persons who were infected and lived with the virus at the time around 2015. The global prevalence rate was 0.51 PLWH per 1000 population.

### 8.5.1 *The Global HIV Epidemic Measured by Headcounts of PLWH*

Table 8.1 lists the 15 countries with the largest number of PLWH. Of these 15 countries, the top five were South Africa, Nigeria, India, Kenya and Mozambique with a total of 15,600,000 PLWH, accounting for 44% of that of the total 148 countries included in the analysis.

Figure 8.1 presents the total counts of PLWH by country. Countries with the largest number of PLWH (dark-red) were located, from left to right, in south and middle Africa, Ukraine, India, China and most other Southeast Asian countries, the United States, and Brazil. Overall, the number of PLWH in these countries ranged from 200,000 to 7000,000.

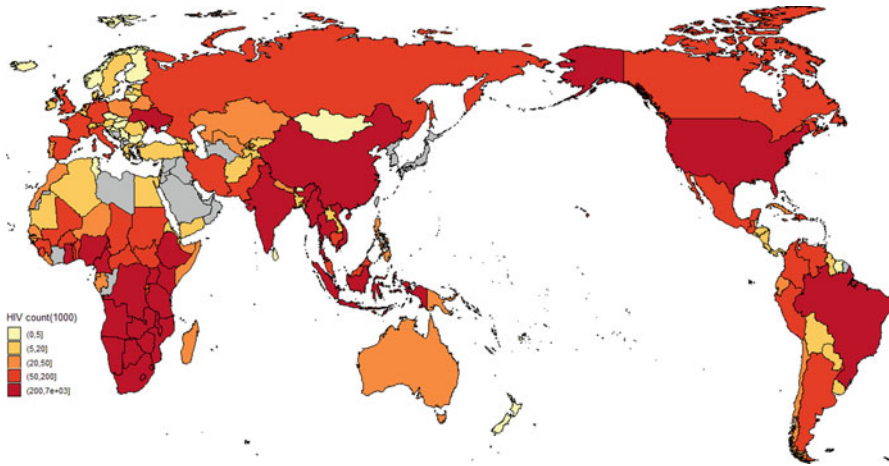
The total number of PLWH provides the information needed for estimating ART cost. One research in South Africa estimates that it costs \$119 to maintain ART per

**Table 8.1** Top 15 countries with the largest number of persons living with HIV (PLWH) in the world, 2013–2015

Name of the country	Continent	PLWH (in 1000)	Rank
South Africa	Africa	7000	1
Nigeria	Africa	3500	2
India	Asia	2100	3
Kenya	Africa	1500	4
Mozambique	Africa	1500	5
Uganda	Africa	1500	6
Tanzania	Africa	1400	7
Zimbabwe	Africa	1400	8
USA	North America	1242	9
Zambia	Africa	1200	10
Malawi	Africa	980	11
China	Asia	850	12
Brazil	South America	830	13
Ethiopia	Africa	794	14
Indonesia	Asia	690	15
World total	–	35,427	–

*PLWH* Persons living with HIV





**Fig. 8.1** The Global HIV epidemic measured by headcount of PLWH (1000), 2013–2015. Note: Grey area data not available

patient per month (Martinson et al., 2009). With this data, for treating one million of PLWH, it will cost \$1.44 billion per year to cover the ART cost alone. It is estimated that there are 7000,000 PLWH in South Africa. To provide ART to them, it will cost the country approximately \$1 trillion per year. To provide ART for the total 35.4 million of PLWH in the 148 countries, a total of \$5+ trillion per year is needed. HIV is by far the one of most expensive diseases (Alistar, Owens, & Brandeau, 2011; CDC, 2017; Martinson et al., 2009).

### 8.5.2 *The Global HIV Epidemic Measured by P Rates of PLWH*

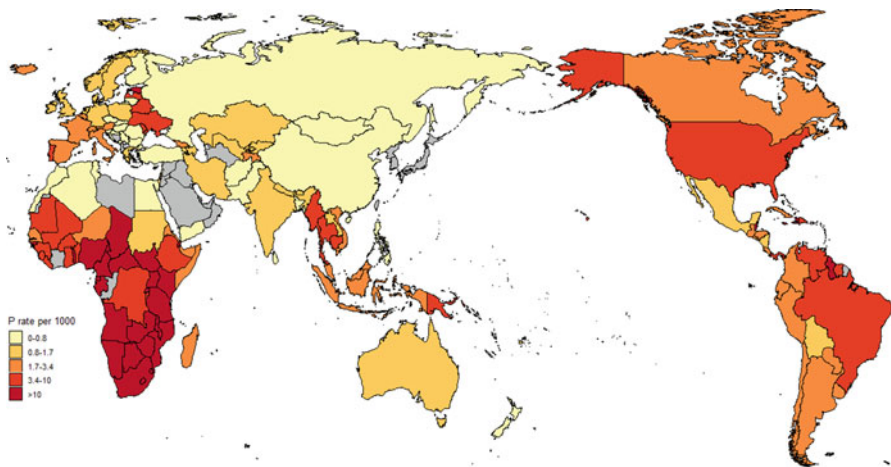
There were large variations in the population among the 148 countries varying from 284,000 for Barbados to 1.37 billion in China. The three countries with the smallest populations were Barbados (284,000), Iceland (319,000) and Belize (359,000); and the three countries with largest population were the United States (0.32 billion), India (1.31 billion) and China (1.37 billion). P rate provides a method to consider these between-country differences in population size for comparisons of the HIV epidemic among countries in the globe.

The 15 countries with highest p rates per 1000 population are listed in Table 8.2. Results in the table indicate that all the 15 countries were located in Africa, and with the total five being Swaziland (170.9/1000), Botswana (154.7/1000), Lesotho (145.2/1000), South Africa (127.4/1000) and Zimbabwe (89.7/1000). The p rate for Swaziland was 33.5 times the average rate of 5.1/1000 for the 148 countries.

**Table 8.2** Top 15 countries with the highest p rates of PLWH, 2013–2015

Name of the country	Continent	P rate (PLWH/1000)	Rank
Swaziland	Africa	170.9	1
Botswana	Africa	154.7	2
Lesotho	Africa	145.2	3
South Africa	Africa	127.4	4
Zimbabwe	Africa	89.7	5
Namibia	Africa	85.4	6
Zambia	Africa	74.0	7
Malawi	Africa	56.9	8
Mozambique	Africa	53.6	9
Uganda	Africa	38.4	10
Kenya	Africa	32.6	11
Equatorial Guinea	Africa	32.0	12
Gabon	Africa	27.2	13
Cameroon	Africa	26.6	14
Tanzania	Africa	26.2	15
Worldwide	–	5.11	–

*PLWH* Persons living with HIV



**Fig. 8.2** The Global HIV epidemic measured by p rates of PLWH (per 1000 population), 2013–2015. Note: *Grey area* data not available

Figure 8.2 presents the p rate mapping of the global HIV epidemic with population size being adjusted. Thus, the map in this figure provides better data than that Fig. 8.1 (headcount) on the risk of HIV epidemic for cross-country comparison. Compared to Fig. 8.1, the first and most striking difference was that several countries with large population and top headcounts of PLWH were no longer on the top list, such as Brazil, China, India, Mexico, Russia, and USA.

Second, most African countries with highest headcounts of PLWH remained the highest with p rates (dark-red). This result suggests the risk of HIV transmission remained high in these countries after considering the population size. Interestingly, two from the lower PLWH-headcount countries moved to the 20% countries with highest p rates (dark-red): Guyana in South America and Estonia in East Europe. These two countries were rather small with regard to population size but the headcounts of PLWH were higher (see Appendix), resulting in high p rates.

By examining the results in Figs. 8.1 and 8.2 and Table 8.1 together, it can be seen first that a country with high PLWH count may not necessarily be the country with high risk of HIV transmission such as Brazil, China, India, Mexico, Russia, and USA. This is because the high counts of PLWH in these countries were primarily due to the large number of populations.

Second, countries with both high PLWH headcounts and high p rates have high risk of HIV transmission, such as most of the African countries with high ranks of both PLWH headcounts and p rates. With more total PLWH and PLWH per 1000 population in these countries, higher risk of HIV spreading is anticipated.

Last, people living in countries with high p rates are at high risk for HIV transmission regardless of PLWH headcounts, such as Guyana and Estonia.

### ***8.5.3 The Global HIV Epidemic Measured by G Rates of PLWH***

The size of geographic area of the 148 countries also varied dramatically from the smallest of 320 km<sup>2</sup> for Malta to the largest of 163,769,000 km<sup>2</sup> for Russia. The total area of the three smallest countries (Malta, Barbados and Singapore) accounted for only 0.001% of the world total; while the total area of the three largest countries (Russia, China and USA) accounts for 28%. Like the p rate for population, g rate provides a measure to gauge the HIV epidemic by adjusting these differences in geographic sizes for cross-country comparisons. This is one of the two new indicators we introduced in this chapter.

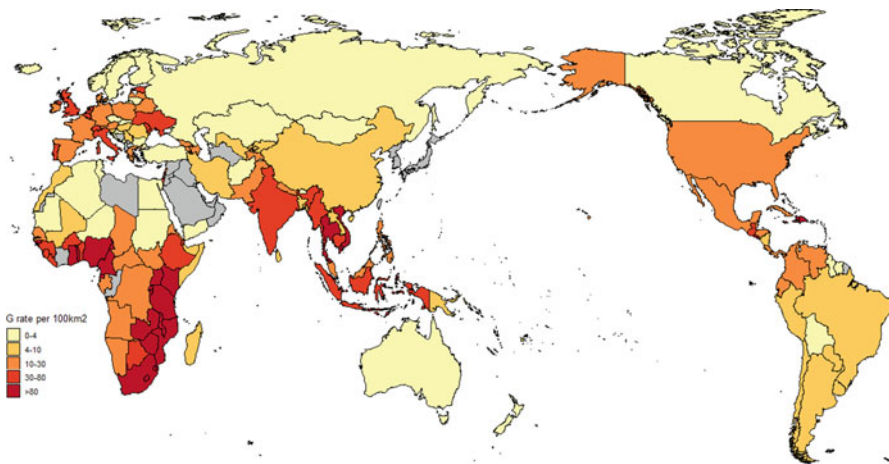
The world average and top 15 countries with highest g rates are listed in Table 8.3. The estimated g rate for Swaziland was 1279.1 PLWH/100km<sup>2</sup>, 44.4 times that of the world average of 28.8. Of the top five countries, three with g rates greater than 1000 PLWH per unit geographic area of 10×10 km<sup>2</sup>.

Figure 8.3 depicts the global HIV epidemic using the estimated g rates of PLWH. Similar to Fig. 8.2, the top 20% countries with highest g rates were colored in dark-red; and these countries were roughly located in three regions of the world. (1) Africa: including a strip of countries from Kenya in the north to South Africa in the south and a small group of countries in the East Africa (Nigeria, Equatorial Guinea, and Cameroon); (2) several countries in Southeast Asia (Singapore, Thailand and Vietnam); and (3) several other countries in Caribbean (Costa Rica, Dominican, Haiti and Jamaica).

**Table 8.3** Top 15 countries with the highest g rates of PLWH, 2013–2015

Name of the country	Continent	G rate (PLWH/100 km <sup>2</sup> )	Rank
Swaziland	Africa	1279.1	1
Malawi	Africa	1039.5	2
Lesotho	Africa	1021.1	3
Rwanda	Africa	810.7	4
Uganda	Africa	748.1	5
Singapore	Asia	697.9	6
Barbados	Africa	604.7	7
South Africa	Africa	577.0	8
Haiti	Africa	471.7	9
Mauritius	Africa	403.9	10
Nigeria	Africa	384.3	11
Zimbabwe	Africa	361.9	12
Burundi	Africa	299.8	13
Jamaica	Gulf of Mexico	267.8	14
Kenya	Africa	263.6	15
Worldwide	–	28.8	–

*PLWH* Persons living with HIV



**Fig. 8.3** The Global HIV epidemic measured by g rates (PLWH/per 100 km<sup>2</sup>). Note: *Grey area* data not available

As expected, g rates were lower for countries with large area sizes even if its PLWH headcount was high, such as Brazil, Canada, China, Russian, and the United States. Given the same area size, higher g rate in a country indicates high risk of HIV transmission because of short distance for personal contact while lower g rate indicates low risk of HIV transmission because of long distance for personal contact.

**Table 8.4** Top 15 countries with the highest pg rates of PLWH (per million population per 100 km<sup>2</sup>), 2013–2015

Name of the country	Continent	PG rate (/million pop. 100 km <sup>2</sup> )	Rank
Barbados	Africa	2127.9	1
Swaziland	Africa	993.8	2
Lesotho	Africa	478.3	3
Malta	Africa	375.0	4
Mauritius	Africa	319.7	5
Bahamas	Caribbean	208.6	6
Trinidad and Tobago	Africa	157.7	7
Cape Verde	Africa	152.6	8
Singapore	Asia	126.9	9
Equatorial Guinea	Africa	113.9	10
Gambia	Africa	104.2	11
Jamaica	Caribbean	98.3	12
Guinea-Bissau	Africa	85.0	13
Luxembourg	Europe	74.5	14
Rwanda	Africa	69.8	15
Worldwide	n/a	0.005	n/a

*PLWH* Persons living with HIV

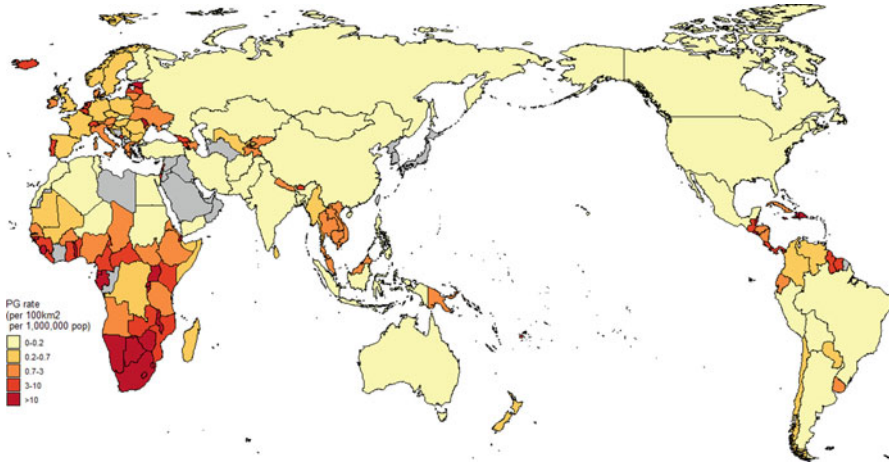
More details about individual countries can be found in Appendix to the end of this chapter.

### 8.5.4 *The Global HIV Epidemic Measured by PG Rates of PLWH*

PG rate is the second new indicator we introduced in this chapter to simultaneously adjust both population size and geographic area. For example, in Fig. 8.3, the United States was categorized into the top 40% countries with the risk of HIV spreading similar to many Caribbean countries, which may not be true, because population size was much large for the United States than for any Caribbean countries. The estimated pg rate indicated that worldwide, there were 0.005 PLWH/million population/100 km<sup>2</sup>.

As usual, Table 8.4 lists the top 15 countries with highest pg rates. Barbados was now the country with the highest pg rate in the world with 2127.9 PLWH per million population per 100 km<sup>2</sup>. This rate was 425,580 times that of the world average and 30 times that of Rwanda, the last one among the top 15. It was not surprise to see this result because of the small area of Rwanda (24,700 km<sup>2</sup>) and population (11,610,000) and a large number of PLWH (an estimate of 200,000).

The global HIV epidemic depicted using pg rates is presented in Fig. 8.4. Results from this figure add addition data better than the headcount, p rate and g rate alone



**Fig. 8.4** The Global HIV/AIDS epidemic measured by pg rates of PLWH (per million persons per 100 km<sup>2</sup>). Note: *Grey area* data not available

to reflect the global pattern of the risk for HIV transmission. Based on the top 40% (colored as dark and light red) with highest pg rates, countries with high threat of HIV epidemic were distributed along with One HIV Hot-Belt and Two HIV Hotspots.

*The HIV Hot Belt:* This belt comprises a list of countries scattered in a band region, the belt starts with Iceland on the top left of the world map, moves across the Euro-Asian, and ends at Papua New Guinea on the bottom right of the map. Other countries on this HIV Hot Belt region were Estonia, Latvia, Netherlands, Belgium, Luxembourg, Switzerland, Montenegro, Portugal, Moldova, Georgia, Armenia, Azerbaijan, Uzbekistan, Kyrgyzstan, Tajikistan, Nepal, Bhutan, Myanmar, Vietnam, Thailand, Laos, Cambodia, Malaysia, and Singapore.

*The HIV Hotspot 1-Africa:* These hotspot comprises all countries in South and Middle Africa except Congo (DRC), Angola, and Tanzania. The majority of these countries was also considered as the places where HIV affects people the most using other three measures.

*The HIV Hotspot 2-Caribbean:* Countries in this hotspot were The Bahamas, Barbados, Belize, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Trinidad and Tobago, Suriname, Venezuela.

## 8.6 Discussion and Conclusion Remarks

In this study, we took a 4D measurement system to describe the global HIV epidemic by adding two newly reported indicators of g rate and pg rate (Chen, 2017; Chen &

Wang, 2017), together with two conventionally used indicators of headcount and p rate. The count and p rate are widely used in research; and the g rate and pg rate add new information, forming a four-dimensional measurement system. We illustrated the utility of the 4D measurement system using HIV data from 148 countries in the world HIV epidemic.

The data about the number of PLWH confirm the conclusion from other studies that it will cost the world a big fortune to end the AIDS epidemic. Providing ART alone for 90% of 36.9 million PLWH in the world will cost \$4.7 trillion per year, based on the estimated cost of \$119 per month for ART in S. African. The estimated lifetime ART cost is \$367,134 per PLWH in the United States (CDC, 2017), which means \$1357 trillion, ~17 times of \$80 trillion, annual GDP produced by all countries in the world. Of the 148 countries included in this study, financial burden will be the greatest for those with highest counts of PLWH, including South African (seven million), Nigeria (3.5million), and India (2.1 million).

Like the p rate to adjust for population size, g rate provides a measure of HIV risk without the influence of the size of a country's geographic area. High g rates suggest greater potentials for close contact between the HIV infected and uninfected persons. Therefore, given the same headcount and p rate, risk of HIV spreading will be higher in countries with high g rates. Singapore provides a best example. This country would be low at HIV transmission if the total number of PLWH (only 4900) and p rate (0.894/1000) were used; however, it became a high-risk country and ranked number 6 in the world when assessed using g rate (126.1 per 1000,000 population per 100 km<sup>2</sup>).

On the contrary, g rates will be small for countries with large land area, such as Russia, Canada, Australia, Brazil, the United States and China. Given the same number of PLWH and the same p rate, the risk will be lower for HIV transmission in countries with smaller g rate since small g rate means longer distances for interpersonal contacts. This is consistent with the rural-urban differences in the HIV epidemic with more infections and quicker growths in urban areas where people crowd together than in rural areas where people reside sparsely (Mnyika et al., 1994). Data generated using g rates of PLWH provide direct evidence supporting the role of geographic area in disease epidemiology in general (Sattenspiel, 2009).

Another innovation is the use of pg rate controlling for both population size and the geographic area. It is an index of the number of PLWH in a given number of population and a geographic area. Thus, pg rates provide the most effective measure for cross-country comparison to assess the risk of transmission of HIV as well as many other infectious diseases. Based on the definition, pg rate will be high for countries with large number of headcount of persons suffering from or died of a disease, but a small population and small geographic area. For example, pg rate was 993.861 for Swaziland, which means roughly 1000 PLWH in every million population residing in an area of 100 km<sup>2</sup>; while the corresponding pg rate was 0.007 for China, indicating much lower risk of HIV transmission. Given all other conditions the same, the likelihood for HIV (or any other infectious disease) to transmit from one to another in a place with small area and a large number of



populations will be greater than in a place with large area and small number of populations.

With pg rate, countries in the region across Middle East and North Africa (MENA) were categorized low risk for HIV transmission. This is consistent with data from different sources (Gokengin, Doroudi, Tohme, Collins, & Madani, 2016) with different interpretations (Abu-Raddad et al., 2010; Gray, 2004). The advantage with our pg rate is that this MENA region looked much smoother and gradually expand to connect with other higher risk regions around, very different from the patterns shown by p rates or headcounts.

Based on pg rates, prevention of HIV transmission should pay particularly high attention to the three regions: One HIV Hot-Belt and two HIV Hotspots to better address the goal set by the UNAIDS to end the AIDS epidemic by 2030 (UNAIDS, 2014b). In general, countries in these high-risk belt and spots are relatively small in geographic area but with a large number of PLWH, in favor of HIV transmission from one to another.

In conclusion, this is the first time a 4D measurement system is formed and tested using the global HIV epidemic. More applications of the same method are highly recommended. For example, the same approach can be used to describe regional differences within a country; and to describe infectious diseases other than HIV. In addition to morbidity, the 4D approach can be used to describe mortality data. The utility of our 4D measurement system integrating headcount, p rate, g rate and pg rate together, providing the most comprehensive measure for researchers and decision makers to grasp the overall pattern of a disease in global health and epidemiology.

### A.1 Appendix 1. List of countries with population, land area, total PLWH, P rate, G rate and PG rate

**Table A.1** List of countries with population, land area, total PLWH, P rate, G rate and PG rate

Country	Population (1000)	Land area (100 km <sup>2</sup> )	PLWH (1000)	P rate (1/1,000)	G rate (1/100 km <sup>2</sup> )	PG rate (1/10 <sup>6</sup> pop× 100 km <sup>2</sup> )
Afghanistan	32527	6,529	6.9	0.212	1.057	0.033
Algeria	39667	23,817	8.8	0.222	0.369	0.009
Angola	25022	12,467	320.0	12.789	25.668	1.026
Argentina	43417	27,367	110.0	2.534	4.019	0.093
Armenia	3018	285	3.6	1.193	12.645	4.190
Australia	23781	76,823	27.0	1.135	0.351	0.015
Austria	8611	825	18.0	2.090	21.812	2.533
Azerbaijan	9651	827	11.0	1.140	13.307	1.379

(continued)



**Table A.1** (continued)

Country	Population (1000)	Land area (100 km <sup>2</sup> )	PLWH (1000)	P rate (1/1,000)	G rate (1/100 km <sup>2</sup> )	PG rate (1/10 <sup>6</sup> pop× 100 km <sup>2</sup> )
Bahamas	388	100	8.1	20.875	80.919	208.544
Bangladesh	160996	1,302	9.6	0.060	7.375	0.046
Barbados	284	4	2.6	9.148	604.651	2,127.480
Belarus	9513	2,029	35.0	3.679	17.249	1.813
Belgium	11286	303	20.0	1.772	66.050	5.853
Belize	359	228	3.6	10.020	15.783	43.927
Benin	10880	1,128	69.0	6.342	61.192	5.624
Bhutan	775	381	1.0	1.291	2.624	3.386
Bolivia	10725	10,833	18.0	1.678	1.662	0.155
Botswana	2262	5,667	350.0	154.697	61.758	27.296
Brazil	207848	83,581	830.0	3.993	9.930	0.048
Bulgaria	7178	1,086	3.9	0.543	3.592	0.501
Burkina Faso	18106	2,736	95.0	5.247	34.722	1.918
Burundi	11179	257	77.0	6.888	299.844	26.822
Cambodia	15578	1,765	74.0	4.750	41.922	2.691
Cameroon	23344	4,727	620.0	26.559	131.159	5.619
Canada	35852	90,935	75.5	2.106	0.830	0.023
Cape Verde	521	40	3.2	6.148	79.404	152.554
Central African Republic	4900	6,230	120.0	24.488	19.262	3.931
Chad	14037	12,592	170.0	12.110	13.501	0.962
Chile	17948	7,435	32.0	1.783	4.304	0.240
China	1371220	93,882	850.0	0.620	9.054	0.007
Colombia	48229	11,095	150.0	3.110	13.520	0.280
Congo, DR	77267	22,671	370.0	4.789	16.321	0.211
Costa Rica	4808	511	10.0	2.080	19.585	4.074
Croatia	4224	560	1.2	0.284	2.144	0.508
Cuba	11390	1,040	22.0	1.932	21.150	1.857
Czech Republic	10551	772	2.1	0.199	2.720	0.258
Côte d'Ivoire	22702	3,180	460.0	20.263	144.654	6.372
Denmark	5676	423	6.1	1.075	14.434	2.543
Djibouti	888	232	9.4	10.587	40.552	45.674
Dominican	10528	483	68.0	6.459	140.758	13.369
Ecuador	16144	2,484	29.0	1.796	11.677	0.723
Egypt	91508	9,955	11.0	0.120	1.105	0.012
El Salvador	6127	207	20.0	3.264	96.525	15.755
Equatorial Guinea Guinea	845	281	27.0	31.950	96.257	113.905
Eritrea	5169	1,010	14.0	2.708	13.861	2.682
Estonia	1312	424	13.5	10.290	31.847	24.274
Ethiopia	99391	10,000	793.7	7.986	79.370	0.799

(continued)

**Table A.1** (continued)

Country	Population (1000)	Land area (100 km <sup>2</sup> )	PLWH (1000)	P rate (1/1,000)	G rate (1/100 km <sup>2</sup> )	PG rate (1/10 <sup>6</sup> pop× 100 km <sup>2</sup> )
Fiji	892	183	1.0	1.121	5.473	6.135
Finland	5482	3,039	2.9	0.529	0.954	0.174
France	66808	5,476	160.0	2.395	29.221	0.437
Gabon	1725	2,577	47.0	27.242	18.240	10.572
Gambia	1991	101	21.0	10.548	207.510	104.228
Georgia	3679	695	9.6	2.609	13.815	3.755
Germany	81413	3,489	73.0	0.897	20.923	0.257
Ghana	27410	2,275	270.0	9.850	118.660	4.329
Greece	10824	1,289	16.0	1.478	12.413	1.147
Guatemala	16343	1,072	55.0	3.365	51.325	3.141
Guinea	12609	2,457	120.0	9.517	48.836	3.873
Guinea-Bissau	1844	281	41.0	22.230	145.804	79.055
Guyana	767	1,969	7.8	10.168	3.962	5.166
Haiti	10711	276	130.0	12.137	471.698	44.038
Honduras	8075	1,119	20.0	2.477	17.875	2.214
Hungary	9845	905	4.1	0.416	4.529	0.460
Iceland	331	1,003	1.0	3.023	0.998	3.015
India	1311051	29,732	2,100.0	1.602	70.631	0.054
Indonesia	257564	18,116	690.0	2.679	38.089	0.148
Iran	79109	16,288	73.0	0.923	4.482	0.057
Ireland	4641	689	7.8	1.681	11.322	2.440
Israel	8380	216	8.5	1.014	39.279	4.687
Italy	60802	2,941	140.0	2.303	47.596	0.783
Jamaica	2726	108	29.0	10.639	267.775	98.232
Kazakhstan	17544	26,997	23.0	1.311	0.852	0.049
Kenya	46050	5,691	1,500.0	32.573	263.556	5.723
Kyrgyzstan	5957	1,918	8.1	1.360	4.223	0.709
Laos	6802	2,308	11.0	1.617	4.766	0.701
Latvia	1978	622	6.8	3.437	10.936	5.528
Lebanon	5851	102	2.4	0.410	23.460	4.010
Lesotho	2135	304	310.0	145.198	1021.080	478.253
Liberia	4503	963	30.0	6.662	31.146	6.916
Lithuania	2910	627	1.5	0.515	2.394	0.823
Luxembourg	570	26	1.0	1.755	38.610	67.775
Madagascar	24235	5,818	48.0	1.981	8.250	0.340
Malawi	17215	943	980.0	56.926	1039.457	60.380
Malaysia	30331	3,286	92.0	3.033	28.002	0.923
Mali	17600	12,202	120.0	6.818	9.835	0.559
Malta	431	3	0.5	1.159	156.250	362.252
Mauritania	4068	10,307	14.0	3.442	1.358	0.334
Mauritius	1263	20	8.2	6.494	403.941	319.925
Mexico	127017	19,440	200.0	1.575	10.288	0.081
Mongolia	2959	15,536	0.5	0.169	0.032	0.011

(continued)

**Table A.1** (continued)

Country	Population (1000)	Land area (100 km <sup>2</sup> )	PLWH (1000)	P rate (1/1,000)	G rate (1/100 km <sup>2</sup> )	PG rate (1/10 <sup>6</sup> pop× 100 km <sup>2</sup> )
Montenegro	622	135	0.5	0.744	3.442	5.531
Morocco	34378	4,463	24.0	0.698	5.378	0.156
Mozambique	27978	7,864	1,500.0	53.614	190.747	6.818
Myanmar	53897	6,531	220.0	4.082	33.687	0.625
Namibia	2459	8,233	210.0	85.406	25.507	10.374
Nepal	28514	1,434	39.0	1.368	27.206	0.954
Netherlands	16937	337	22.1	1.305	65.598	3.873
New Zealand	4596	2,633	2.9	0.631	1.101	0.240
Nicaragua	6082	1,203	9.9	1.628	8.227	1.353
Niger	19899	12,667	49.0	2.462	3.868	0.194
Nigeria	182202	9,108	3,500.0	19.209	384.290	2.109
Norway	5196	3,652	4.5	0.866	1.232	0.237
Pakistan	188925	7,709	100.0	0.529	12.972	0.069
Panama	3929	743	17.0	4.327	22.868	5.820
Papua New Guinea	7619	4,529	40.0	5.250	8.833	1.159
Paraguay	6639	3,973	17.0	2.561	4.279	0.645
Peru	31377	12,800	66.0	2.103	5.156	0.164
Philippines	100699	2,982	42.0	0.417	14.086	0.140
Poland	37999	3,062	35.0	0.921	11.431	0.301
Portugal	10349	916	48.0	4.638	52.399	5.063
Moldova	3554	329	18.0	5.065	54.761	15.408
Romania	19832	2,301	16.0	0.807	6.954	0.351
Russian	144097	163,769	73.0	0.507	0.446	0.003
Rwanda	11610	247	200.0	17.227	810.701	69.830
Senegal	15129	1,925	46.0	3.040	23.892	1.579
Serbia	7098	875	3.5	0.493	4.002	0.564
Sierra Leone	6453	722	51.0	7.903	70.657	10.949
Singapore	5535	7	4.9	0.894	697.884	126.086
Slovakia	5424	481	0.5	0.092	1.040	0.192
Slovenia	2064	201	1.0	0.485	4.965	2.406
Somalia	10787	6,273	30.0	2.781	4.782	0.443
South Africa	54957	12,131	7,000.0	127.372	577.039	10.500
South Sudan	12340	6,197	180.0	14.587	29.044	2.354
Spain	46418	5,002	150.0	3.231	29.987	0.646
Sri Lanka	20966	627	4.2	0.200	6.697	0.319
Sudan	40235	23,760	56.0	1.392	2.357	0.059
Suriname	543	1,560	3.8	6.998	2.436	4.486
Swaziland	1287	172	220.0	170.944	1279.070	993.861
Sweden	9799	4,073	9.1	0.929	2.234	0.228
Switzerland	8287	395	20.0	2.413	50.612	6.108
Tajikistan	8482	1,388	16.0	1.886	11.529	1.359
Thailand	67959	5,109	440.0	6.474	86.124	1.267

(continued)

**Table A.1** (continued)

Country	Population (1000)	Land area (100 km <sup>2</sup> )	PLWH (1000)	P rate (1/1,000)	G rate (1/100 km <sup>2</sup> )	PG rate (1/10 <sup>6</sup> pop×100 km <sup>2</sup> )
Togo	7305	544	110.0	15.059	202.243	27.687
Trinidad and Tobago	1360	51	11.0	8.088	214.425	157.655
Tunisia	11108	1,554	2.6	0.234	1.674	0.151
Turkey	78666	7,696	5.5	0.070	0.715	0.009
Uganda	39032	2,005	1,500.0	38.430	748.055	19.165
Ukraine	45198	5,793	220.0	4.867	37.978	0.840
UK	65138	2,419	101.2	1.554	41.830	0.642
Tanzania	53470	8,858	1,400.0	26.183	158.049	2.956
USA	321419	91,474	1,242.0	3.864	13.578	0.042
Uruguay	3432	1,750	10.0	2.914	5.714	1.665
Uzbekistan	31300	4,254	33.0	1.054	7.757	0.248
Venezuela	31108	8,821	110.0	3.536	12.471	0.401
Vietnam	91704	3,101	260.0	2.835	83.852	0.914
Yemen	26832	5,280	9.2	0.343	1.743	0.065
Zambia	16212	7,434	1,200.0	74.020	161.423	9.957
Zimbabwe	15603	3,869	1,400.0	89.728	361.897	23.191

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